Estimation of hull forces in low-level still water manoeuvring mathematical models

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SHOPERA Meeting in Duisburg

16—17 March 2015

Relevance and questions

- **Lower-level models for ship manoeuvring in waves contain the still-water component and are supposed to be reduced to it at zero wave amplitude**
- **Necessary for working out manoeuvrability criteria in wind**
- **Can be combined with hydrodynamic interaction models**

- **Question 1: What is the minimum acceptable complexity?**
- **Question 2: How reliable can be hull forces predictions?**
- **Question 3: Is it possible to make low-level estimates reasonably conservative?**

3 DOF model

- **Minimum recommended complexity:**

$$(m+\mu_{11})\dot{u} - mvr - mx_G r^2 = X,$$

$$(m+\mu_{22})\dot{v} + (mx_G + \mu_{26})\dot{r} + mur = Y,$$

$$(mx_G + \mu_{26})\dot{v} + (I_{zz} + \mu_{66})\dot{r} + mx_G ur = N,$$

$$\dot{\xi} = u\cos\psi - v\sin\psi,$$

$$\dot{\eta} = u\sin\psi + v\cos\psi,$$

$$\dot{\psi} = r.$$

- **Comments:**

1. **The added masses can be estimated reasonably accurately**
2. **Is further simplification $(x_G = \mu_{26} = 0)$ possible? Yes but not desirable as long as x_G is usually known and the simplification is insignificant**
3. **Quasi-steady hydrodynamic forces must be estimated using minimum number of shape parameters with acceptable uncertainty (what is this?)**

Quasi-steady forces $F = X, Y, N$

1. **Holistic approach:** $F = F(u - u_0, v, r, n, \delta_R)$
   a. Is typically associated with the Abkowitz (or similar) polynomials
   b. **Advantages:** all interaction effects are accounted for automatically, is structurally simple though with increased number of regression coefficients (model parameters)
   c. **Disadvantage:** no systematic databases have ever been created, existing collections are proprietary and partly lost ➔ impossible to use the approach without preliminary tests/CFD computations for a defined hull form ➔hardly suitable for low-level methods
2. **Modular approach:** $F = F_H + F_P + F_R$
   a. Several database or Munk+cross-flow-drag methods exist for Hull forces
   b. The Propeller thrust (1 quadrant) can be estimated with the Oosterveld—Oossanen polynomials --- this is the simplest acceptable method
   c. The Rudder forces will be commented in a separate communication

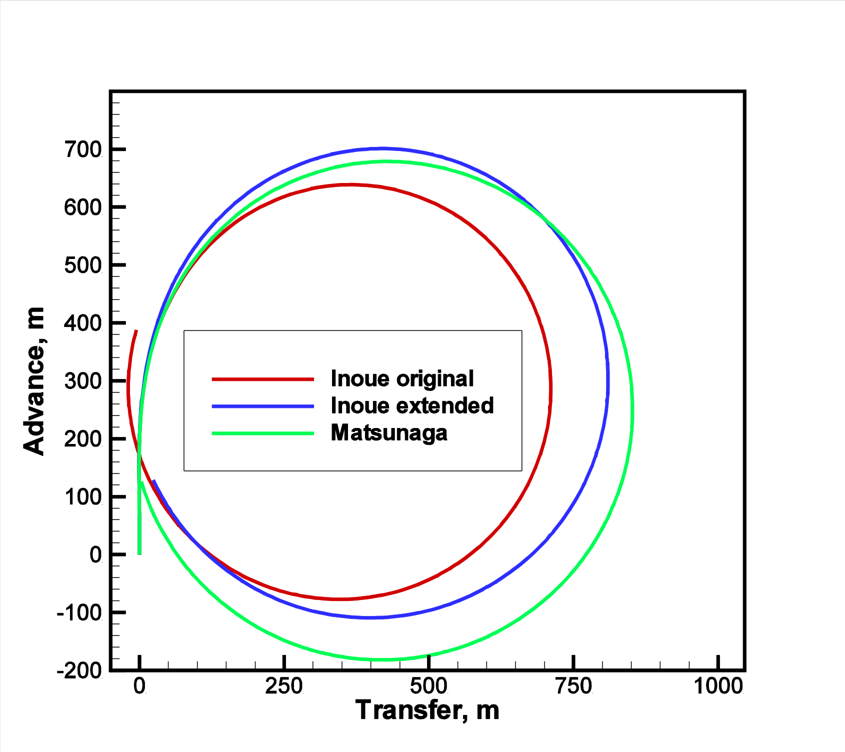
Empiric methods for hull forces

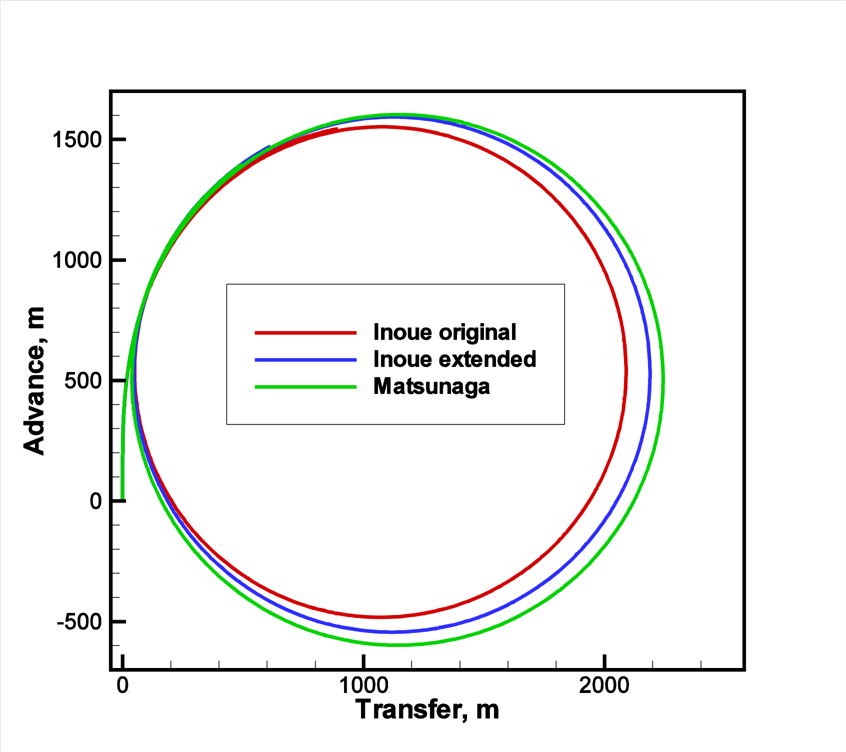
- **First empiric methods based on more or less systematic tests with scaled models of hulls appeared in 50—60s but nowadays, regarding mearchant ships, methods of the MMG family are preferable.**
- **The latest version "Standard MMG method" (Yasukawa & Yoshimura 2014) presumes carrying out PMM tests in each case ➔ unsuitable as low level method.**
- **Inoue et al. (1981): is 4DOF; the resistance curve is supposed to be known; sway and yaw forces represented with simple polynomials depend on C_B, several dimensionless combinations of the main particulars, and on the trim. Extended by Sutulo (1994) to 4 quadrants**
- **Matsunaga (1993): 3DOF, somewhat different nonlinear part, empiric shallow-water corrections**
- **Kijima (2003): additional geometric parameters describing the shape of the stern**

Turns with empiric methods

35 deg helm

5 deg helm



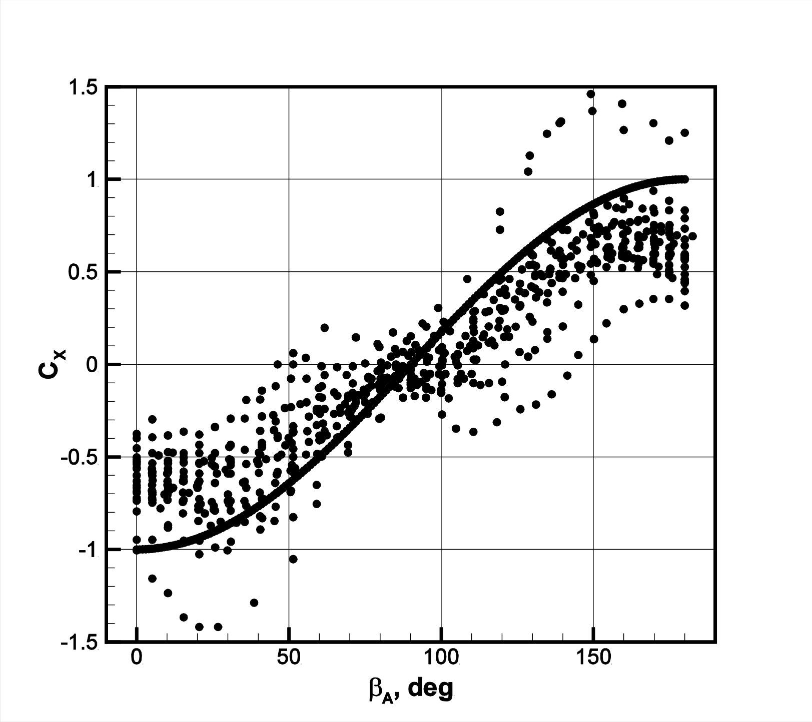


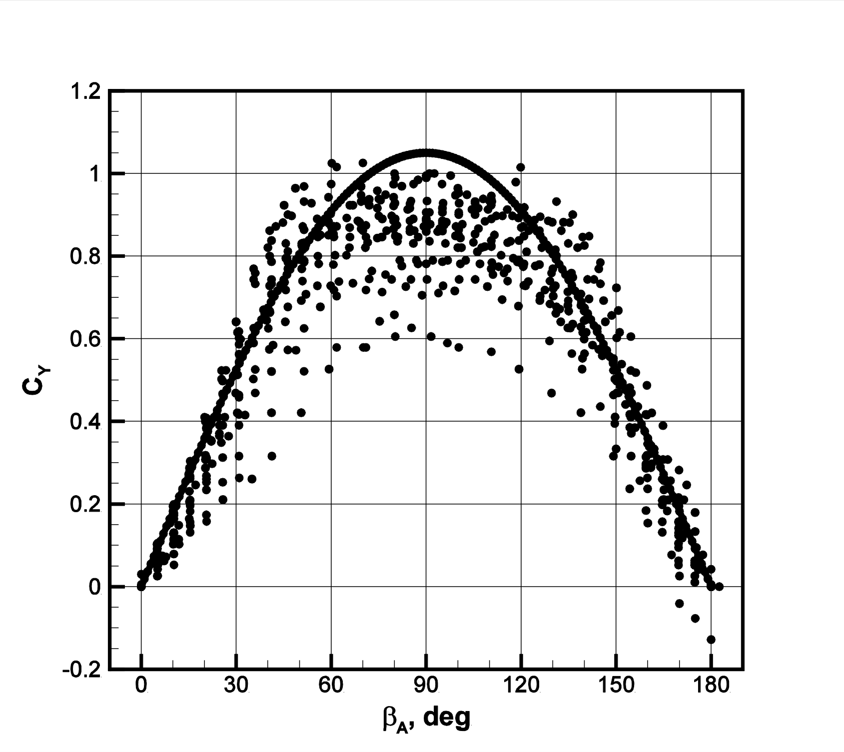
Possibilities of empiric methods

- **All existing empiric methods suffer from considerable uncertainties which is quite natural: compare with hull residual resistance databases. Increased complexity of the manoeuvring problem does not leave hopes for a different situation.**
- **For accurate predictions, CFD computations or model tests are necessary --- higher level methods.**
- **Is it possible, at least, to make low-level predictions of the hull hydrodynamic forces conservative? In theory---yes but in practice---unlikely: definitely, the margin will be too large.**
- **However, empiric methods provide qualitatively consistent results and can be used for standardizing purposes as long as the final criteria are faired with those observed on existing ships**

Estimation of aerodynamic forces

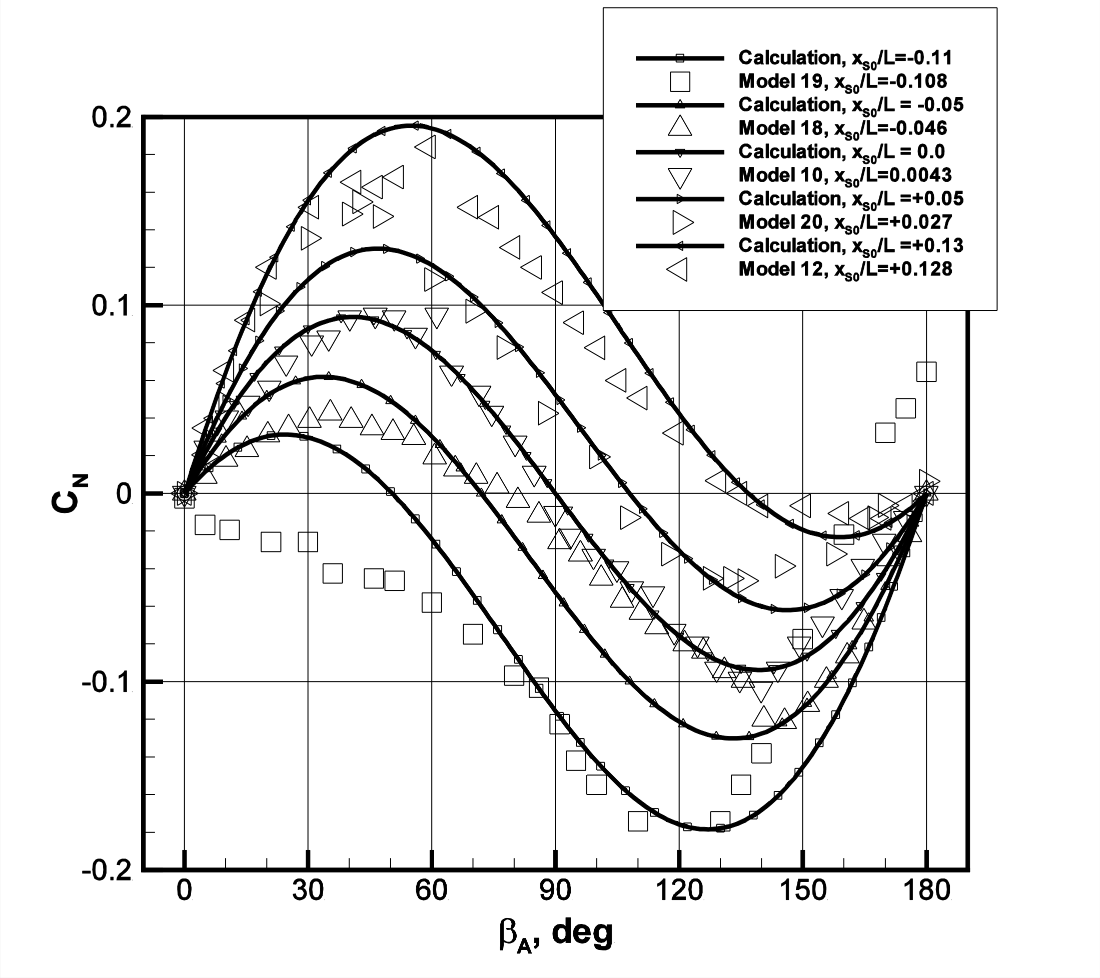
- **A very old generic model:** $C_{XA} = -C_{X0} \cos \beta_A, \quad C_{YA} = C_{Y0} \sin \beta_A,$





Aerodynamic yaw moment

$$C_{NA} = C_{YA} x'(\beta_A); \quad x'_A = \frac{x_{A0}}{L_{OA}} + \frac{1}{4} - \frac{|\beta_A|}{2\pi}$$



Conclusions

1. **Low-level model of minimum complexity is 3DOF, with O&O propeller model (too simplistic formulae for, say, bollard pull must not be used), using some empiric method for the hull forces.**
2. **Modification of parameters for hydrodynamic hull forces aiming at guaranteeing conservative estimates is problematic.**
3. **However, apparently, a method for conservative (upper limit) estimation of aerodynamic loads can be devised.**

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